AN ECONOMIC STUDY OF THE HOT-CARBONATE PROCESS FOR REMOVING CARBON DIOXIDE

By Sidney Katell and John H. Faber

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by

Sidney Katell[2] and John H. Faber[3]

SUMMARY AND CONCLUSIONS

This study presents the economics of the hot-carbonate purification process for removing CO_2. It considers three variations of the process in order to meet the design specifications, which call for a feed-gas flow of 10 million standard cubic feet per hour (std.c.f.h.) with CO_2 inlet concentrations of 10, 20, and 30 percent and exit CO_2 values of 5, 2, 1, 0.5, and 0.1 percent. Inlet pressure and temperature are 350 pounds per square inch gage (p.s.i.g.) and 300° F., respectively.

Estimated capital and operating costs are shown in the following tabulations:

Capital cost

Exit gas, CO_2 concentration, percent	Feed gas, CO_2 concentration, percent		
	10	20	30
5	$1,131,200	$2,191,900	$3,507,300
2	1,718,600	3,057,300	4,332,400
1	2,186,000	3,559,500	4,926,700
.5	2,515,100	3,879,800	5,379,900
.1	2,828,400	4,198,800	6,033,800

Operating cost, cents per thousand standard cubic foot of feed gas

Exit gas, CO_2 concentration, percent	Feed gas, CO_2 concentration, percent		
	10	20	30
5	0.74	1.25	1.80
2	.96	1.45	1.99
1	1.08	1.59	2.15
.5	1.13	1.62	2.18
.1	1.19	1.70	2.33

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The major items in the operating cost are regeneration steam, electric power, labor, and depreciation. Steam is 40 to 50 percent of the total operating cost; depreciation and power are 15 to 20 percent each. The remaining 35 to 45 percent is charged to cooling water, labor, maintenance, payroll overhead, supplies, and indirect cost.

INTRODUCTION

The hot-potassium-carbonate purification process for removing carbon dioxide in synthesis gas was developed by the Bureau of Mines.[4,5] Its application to various industrial gases is rapidly increasing both in this country and abroad. Several recent articles[6,7,8,9,10,11] have been written that discuss the process and, to some extent, the conomics of the operation. However, this information has been limited to systems of up to 100 million standard cubic feet per day (std.c.f.d.) (60° F., 30 inches Hg, dry) of feed gas. This study extends the scope of these data to a feed system of 240 million std.c.f.d. operating at a pressure of 350 p.s.i.g. and an inlet temperature of 300° F. with an initial CO_2 content of 10, 20, and 30 percent. CO_2 specifications for the exit gas from the purification system were set at 5, 2, 1, 0.5, and 0.1 percent.

Any purification system--amine, hot carbonate, water, or other--has its own optimum range of application. The hot carbonate process is best applied at pressures above 200 p.s.i.g. and to a gas with CO_2 concentrations above 10 percent. There are exceptions to this rule, but the designated limits usually will apply.

The hot-carbonate process and the more widely used amine process for removing CO_2 are similar in many respects. The principal items of equipment such as absorbers, regenerators, and solution pumps are essentially the same. The two factors that account for the major differences in the two systems are

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[4] Benson, H. E., Field, J. H., and Jimeson, R. M., CO_2 Absorption Employing Hot Potassium Carbonate Solutions: Chem. Eng. Prog., vol. 50, July 1954, pp. 356-364.

[5] Benson, H. E., Field, J. H., and Haynes, W. P., Improved Process for CO_2 Absorption Uses Hot Carbonate Solutions: Chem. Eng. Prog., vol. 52, October 1956, pp. 433-438.

[6] Buck, B. O., and Leitch, Angus R. S., CO_2 Removal From Natural Gas: Oil Gas Jour., vol. 56, No. 38, Sept. 22, 1958, pp. 99-104.

[7] Palo, Robert O., and Armstrong, John B., How CO_2 Removal Plants Are Working: Petrol. Refiner, vol. 37, December 1958, pp. 123-128.

[8] Eickmeyer, A. G., Acid-Gas Removal by the Hot-Carbonate Method: Oil Gas Jour., vol. 56, No. 38, Sept. 22, 1958, pp. 106-111.

[9] Mullowney, J. F., Which CO_2 Removal Scheme is Best?: Petrol. Refiner, vol. 36, December 1957, pp. 149-152.

[10] Oil and Gas Journal, How CO_2 is Removed by the Hot Potassium-Carbonate Process: Vol. 56, No. 6, Feb. 10, 1958, pp. 98-99.

[11] Gas Age, New Lone Star Gas Treating Plant Will Use Hot Potash-Amine Method: Vol. 121, No. 4, Feb. 20, 1958, pp. 39, 42.

the size of liquid-heat exchangers and steam requirements. In the hot-carbonate system both absorption and regeneration occur at relatively the same temperature, the temperature differential depending on the cycle used. Therefore, when compared with amine purification, the heat exchanger is either smaller or completely eliminated. With amine, the liquid-heat exchangers might involve 20 percent of the capital investment, depending upon design conditions.

The regeneration efficiency (CO_2 removed per pound of steam used), using hot carbonate, is higher than with amine, and this, with lower cooling-water requirements and elimination of exchangers, explains the lower operating cost of the hot-carbonate process.

Another advantage of hot carbonate is its ability to remove both H_2S and COS in addition to the CO_2. The quantity of sulfur removal is related to the quantity of CO_2 removed in the system. This relationship will be discussed in a separate report.

Three variations of the hot-carbonate process are used in this study. They are (1) single-stream operation, (2) split-stream operation, and (3) two-stage operation. Simplified flow diagrams of these processes are shown in figure 1.

PROCESS DESCRIPTION

Single-Stream or Conventional Operation

The single-stream operation is best suited for removing CO_2 down to 2 percent in the exit gas. The feed gas enters the base of the Raschig-ring-packed absorber flowing countercurrent to a 35-percent potassium carbonate solution entering the top of the unit. The foul solution from the bottom of the absorber enters the top of the packed regenerator where the acid gases are removed by means of stripping steam. The regenerated solution is then pumped back to the top of the absorber.

The treated gas is sent on for further processing or, with a natural gas installation, is cooled for pipeline transmission.

Split-Stream Operation

In the split-stream operation used for removing CO_2 down to 1 percent, the feed gas follows the same flow pattern as in the single stream. The difference between the two systems is that, in the split stream, part of the solution leaving the regenerator (approximately one-third) is cooled and then pumped to the top of the absorber. The remaining two-thirds is not cooled and is fed to the absorber somewhere near the midway point. In the split-stream system the tower is higher and the liquid loading is lower in comparison with the single-stream operation.

Two-Stage Operation

The two-stage purification process for systems operating with a CO_2 outlet below 1 percent utilizes a split-stream operation in both the absorber and

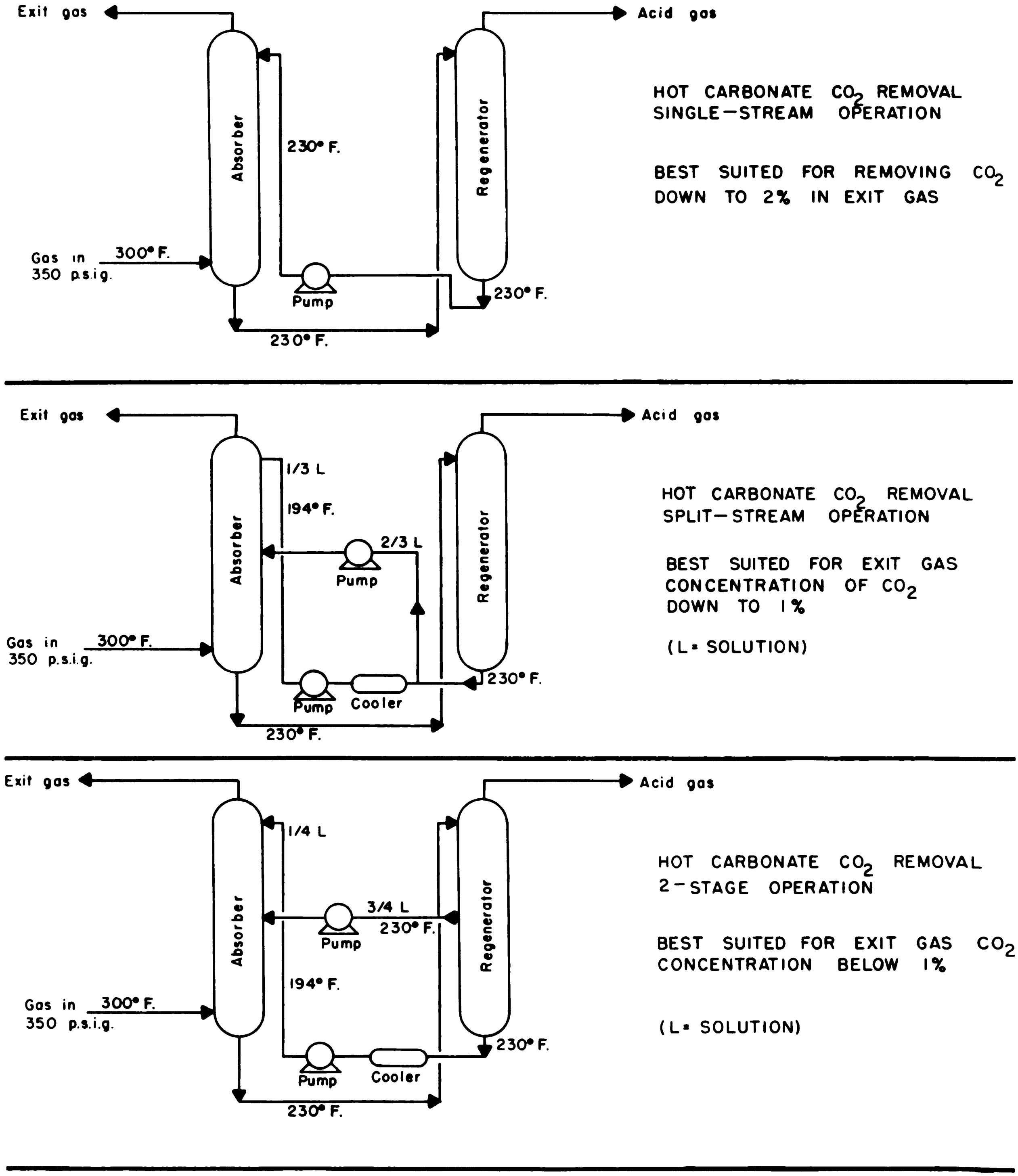

FIGURE 1.—Process Flowsheets.

regenerator. The feed gas follows the same flow pattern as in the single- and split-stream processes. The carbonate solution flow differs in that 75 percent of the solution, drawn from a midpoint on the reactivator after being partly regenerated, is fed to the absorber near its midpoint. The other 25 percent is fully regenerated, cooled, and then fed to the top of the tower.

ESTIMATED CAPITAL AND OPERATING COSTS

Tables 1, 2, and 3 list both the capital and operating costs for the purification systems as designed for the conditions previously outlined. These tables include additional pertinent utility requirements. Table 4 lists the various design factors used in preparing this study. In the design of both the absorber and regenerator, a closer approach to equilibrium between the gas and the solution was assumed, resulting in an optimum steam requirement. Figure 2 shows graphically the relationship between capital investment and inlet and outlet CO_2 concentrations. Similarly, the operating costs are shown in figure 3.

TABLE 1. - Data summary, 30-percent CO_2 inlet, 10 million std.c.f.h. gas feed

Process................	Single stream		Split stream	Two stage	
Exit gas, CO_2 concentration, percent......	5	2	1	0.5	0.1
Capital investment.dol.	3,507,300	4,332,400	4,926,700	5,379,900	6,033,800
Operating cost[1].......	1.80	1.99	2.15	2.18	2.33
Horsepower required....	3,810	4,430	4,260	4,140	4,110
Cooling water....g.p.m.	17,000	18,500	25,590	23,900	26,100
Steam required..lb./hr.	292,000	317,400	348,600	353,000	383,720
K_2CO_3.............$/yr.	28,100	30,500	31,300	30,000	30,300

[1] Cents per 1,000 std.c.f. feed gas, without return on investment.

TABLE 2. - Data summary, 20-percent CO_2 inlet, 10 million std.c.f.h. gas feed

Process................	Single stream		Split stream	Two stage	
Exit gas, CO_2 concentration, percent......	5	2	1	0.5	0.1
Capital investment.dol.	2,191,900	3,057,300	3,559,500	3,879,800	4,198,800
Operating cost[1].......	1.25	1.45	1.59	1.62	1.70
Horsepower required....	2,237	2,875	2,970	2,852	2,755
Cooling water....g.p.m.	10,200	11,900	16,976	16,150	17,372
Steam required..lb./hr.	175,500	204,400	228,500	233,300	255,100
K_2CO_3.............$/yr.	17,900	20,800	21,700	21,000	20,200

[1] Cents per 1,000 std.c.f. feed gas, without return on investment.

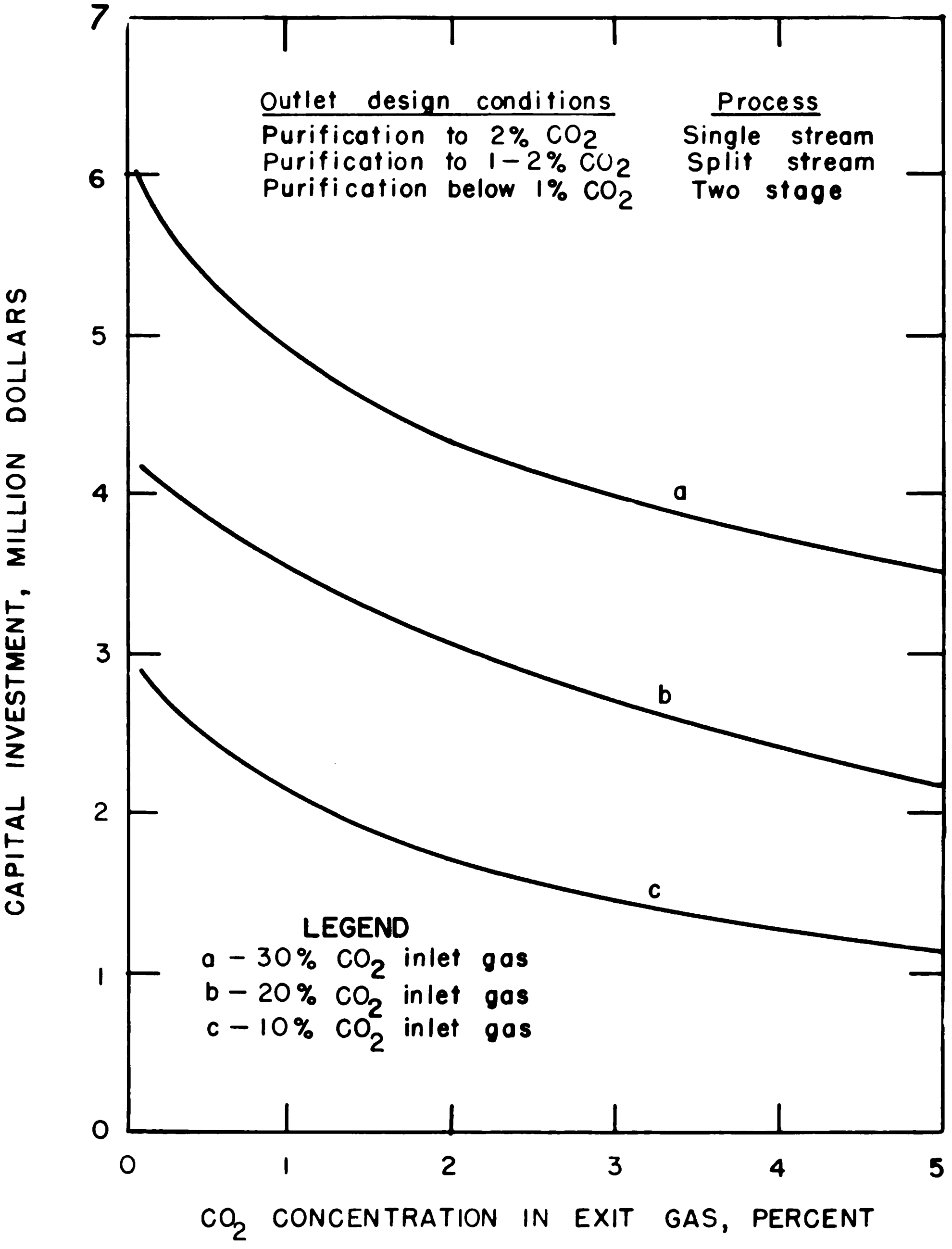

FIGURE 2.—Relationship of Capital Investment and Exit Gas Concentration for Hot-Carbonate System.

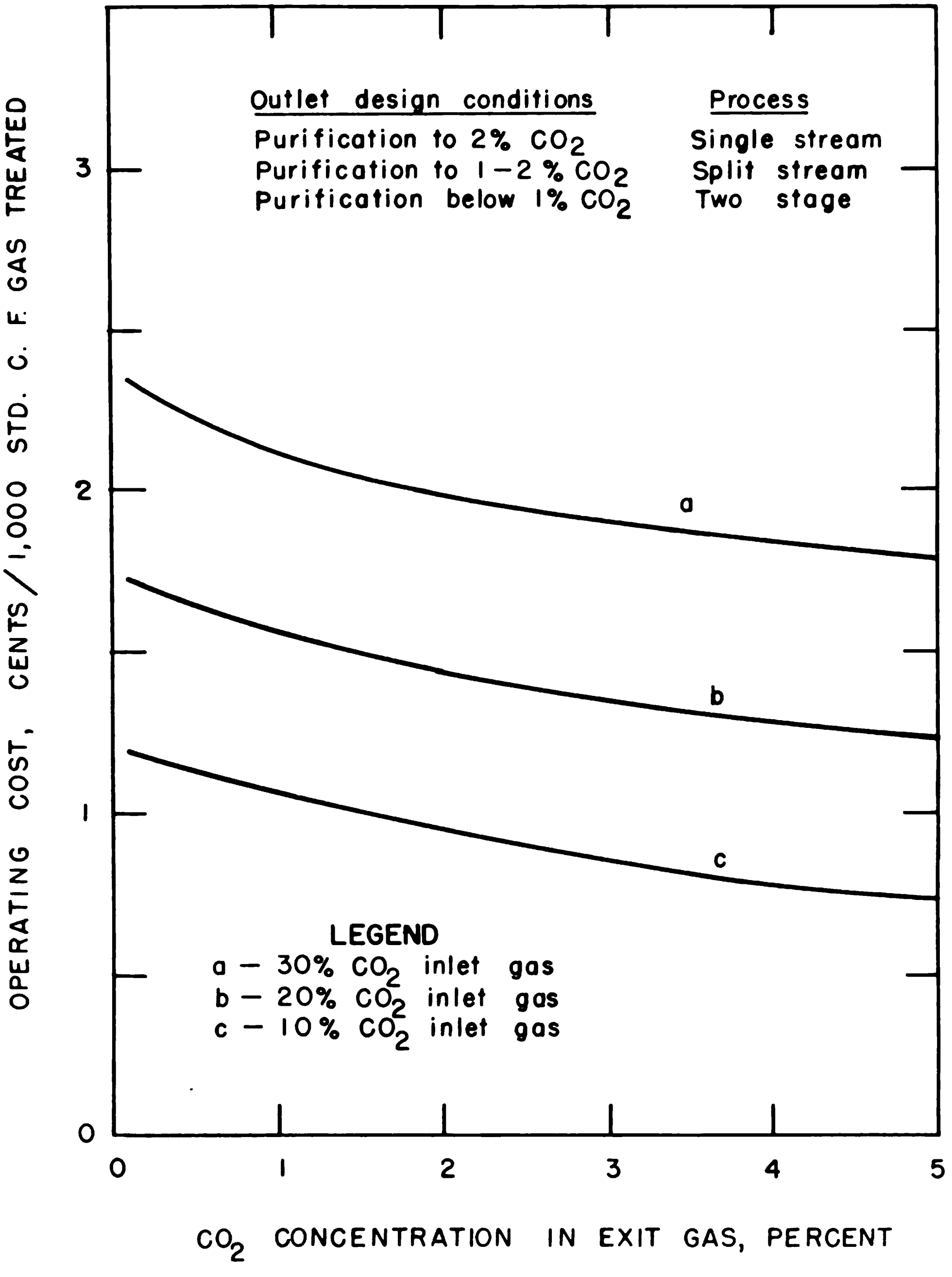

Figure 3.—Relationship of Operating Cost and Exit Gas Concentration for Hot-Carbonate System.

TABLE 3. - Data summary, 10 percent CO_2 inlet, 10 million std.c.f.h. gas feed

Process	Single stream		Split stream	Two stage	
Exit gas, CO_2 concentration, percent	5	2	1	0.5	0.1
Capital investment..dol.	1,131,200	1,718,600	2,186,000	2,515,100	2,828,400
Operating cost[1/]	0.74	0.96	1.08	1.13	1.19
Horsepower required	964	1,525	1,684	1,677	1,670
Cooling water.....g.p.m.	3,550	6,140	9,470	9,340	10,070
Steam required...lb./hr.	61,200	106,000	128,000	134,500	147,900
K_2CO_3..............\$/yr.	7,000	10,800	12,100	12,300	11,900

[1/] Cents per 1,000 std.c.f. feed gas, without return on investment.

The required equipment includes absorbers, regenerators, hot-carbonate pumps, reflux and makeup pump, carbonate-mix tank, carbonate-storage tank, clean-gas knockout drums, centrifuge reboilers, acid-gas coolers, and acid-gas knockout drum. All equipment is carbon steel except the hot-carbonate pumps, solution coolers, and reboiler tubes, which are Type 304 stainless. To the cost of the principal items of equipment are added the cost of foundations, structures, buildings, insulation, instrumentation, piping, electrical work, and painting.

The complete cost includes indirect field labor, engineering, overhead, and administration with a contingency factor.

The method used to calculate the operating cost is illustrated in table 5. The authors realize that bookkeeping and accountant methods differ with companies; therefore, adjustments of any items that enter into the calculations may be necessary for any specific application. One major cost item, the return on investment, was not considered, since the range of anticipated return depends on the particular operator of the hot-carbonate purification system.

For this study a 90-percent operating factor or a 330-day operating year was assumed. Actually, the unit should be capable of a 96-percent onstream factor. Again, this would depend on a specific installation.

TABLE 4. - Hot-carbonate-purification system, basic design factors

Feed gas, CO_2 concentration, percent	Exit gas, CO_2 concentration, percent	Process		Absorber L,[1] [2] lb./hr.-ft.^{2}	Tower packing height, ft.		CO_2 pickup ft.^{3}/gal.	Regeneration ft.^{3} CO_2/lb. steam
		Absorber	Regenerator		Absorber	Regenerator		
30	5	Single stream	Single stream	21,000	32	40	3.6	9.0
30	2	.....do......	.....do......	18,000	40	50	3.6	9.0
30	1	Split stream.	.....do......	18,000	50	50	3.6	8.4
30	.5	.....do......	Split stream.	17,000	50	60	3.8	8.4
30	.1	.....do......	.....do......	16,000	60	60	3.8	7.8
20	5	Single stream	Single stream	20,000	30	40	3.4	9.0
20	2	.....do......	.....do......	17,000	40	50	3.4	9.0
20	1	Split stream.	.....do......	17,000	50	50	3.4	8.4
20	.5	.....do......	Split stream.	16,000	50	60	3.6	8.4
20	.1	.....do......	.....do......	15,000	60	60	3.8	7.8
10	5	Single stream	Single stream	20,000	26	40	2.9	8.6
10	2	.....do......	.....do......	15,000	40	50	2.9	7.7
10	1	Split stream.	.....do......	15,000	50	50	2.9	7.1
10	.5	.....do......	Split stream.	13,500	50	60	3.0	7.1
10	.1	.....do......	.....do......	12,000	60	60	3.2	6.7

[1] L = Liquid flow in lb./hr.-ft.^{2} of tower cross section.
[2] Regenerator L about 9,000 lb./hr.-ft.^{2} in all instances.

TABLE 5. - Hot-carbonate-purification system, estimated annual operating cost, 30 percent CO_2 in, 5 percent CO_2 out

Capital investment - $3,507,300

		Percent
Direct cost:		
(a) Raw materials and utilities:		
Electric--2,990 kw.-hr. x 24 x 330 x $0.0075/kw.-hr.	$177,700	
Cooling water--17,000 g.p.m. x 60 x 24 x 330 x $0.01/1,000 gal	80,800	
K_2CO_3 (annual replacement)	28,100	
Steam--292,000 lb./hr. x 24 x 330 x $0.25/1,000 lb.	578,200	
	864,800	60.6
(b) Direct labor:		
96 man-hours at $2.25 x 365	78,800	
Supervision at 15 percent	11,800	
	90,600	6.3
(c) Plant maintenance:		
10 men at $5,000 per annum	50,000	
Supervision at 20 percent	10,000	
Material, 50 percent of labor	25,000	
	85,000	6.0
(d) Payroll overhead (18.5 percent of payroll)	27,900	2.0
(e) Operating supplies (20 percent of plant maintenance)	17,000	1.2
Total direct cost	1,085,300	76.1
Indirect cost:		
50 percent labor, maintenance, and supplies	96,300	6.7
Fixed cost:		
Local taxes and insurance at 2 percent of capital investment	70,100	4.9
Depreciation at 5 percent of capital investment	175,400	12.3
Total operating cost	1,427,100	100.0

Total gas feed to unit = $10 \times 10^6 \times 24 \times 330 = 79.2 \times 10^9$ std.c.f.

Operating cost per 1,000 std.c.f. $= \frac{\$1,427,100}{79.2 \times 10^6} = \$0.018$

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